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Affordable, Robust Ceramic Joining Technology (ARCJoinT)

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Joining is recognized as one of the enabling technologies for the application of silicon carbide-based ceramic and composite components in a number of demanding and high temperature applications in aerospace and ground-based systems. An affordable, robust ceramic joining technology (ARCJoinT) for joining of silicon carbide-based ceramics and fiber reinforced composites has been developed. This technique is capable of producing joints with tailorable thickness and composition. A wide variety of silicon carbide-based ceramics and composites, in different shapes and sizes, have been joined using this technique. These joints maintain their mechanical strength up to 1350°C in air. This technology is suitable for the joining of large and complex shaped ceramic and composite components and with certain modifications, can be applied to repair of ceramic components damaged in service.

Silicon carbide-based ceramics and fiber reinforced composites are either currently being used or are under active consideration for use in a wide variety of high temperature applications within the aeronautics, energy, electronics, nuclear, and transportation industries. These materials are being developed for engine components, radiant heater tubes, heat exchangers, heat recuperators, and components for land based power generation turbines. Other applications include the first wall and blanket components of fusion reactors, furnace linings and bricks, and components for diffusion furniture (boats, tubes) in the microelectronics industry. The engineering designs require fabrication and manufacturing of complex shaped parts which are quite expensive. In many instances, it is more economical to build up complex shapes by joining together simple geometrical shapes. Thus, joining has been recognized as one of the enabling technologies for successful utilization of silicon carbide-based ceramic and fiber reinforced composite components in high temperature applications. However, the joints must have good mechanical strength and environmental stability, comparable to the bulk materials. These joints must also retain their structural integrity at high temperatures. In addition, the joining technique should be robust, practical, and reliable. For electronics applications, joint composition can also be critical.

Currently Used Joining Techniques:

Overviews of various joining techniques, e.g., mechanical fastening, adhesive bonding, welding, brazing, and soldering have been provided in recent publications [1-5]. The majority of the techniques used today are based on the joining of monolithic ceramics and fiber reinforced composites with metals and ceramics either by diffusion bonding, metal brazing, brazing with oxides and oxynitrides, or diffusion welding. Some of these techniques require high temperatures

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either for processing or hot pressing. In other instances, the joint use temperatures are lower than the temperature capability of the base ceramics or composites. The joints produced by brazing techniques can have different thermal expansion coefficients than the parent materials, which contributes to stress concentration in the joint area. Normally, the use temperatures for brazed joints is limited to ~700 °C.

Ceramic joint interlayers have been developed as a means of obtaining high temperature joints. These joint interlayers have been produced via pre-ceramic polymers, in-situ displacement reactions, and tape casting/reaction bonding techniques [4]. Joints produced by the pre-ceramic polymer approach exhibit significant amounts of porosity, low crystallinity, and poor mechanical properties. On the other hand, hot pressing or high temperature fixtures are needed for in-situ displacement reactions, diffusion bonding, and tape casting-reaction bonding techniques. Due to the equipment required, these techniques are not well suited for joining large or complex shaped components.

ARCJoinT, which is based on the reaction forming approach, is unique in terms of producing joints with tailorable microstructures. The formation of joints by this approach is attractive since the thermomechanical properties of the joint interlayer can be tailored to be very close to those of the silicon carbide base materials. In addition, high temperature fixturing is not needed to hold the parts at the infiltration temperature. A variety of silicon carbide-based ceramics and fiber reinforced composites have been joined using this approach [6-11].

ARCJoinT:

Processing

A process flow diagram of the affordable, robust ceramic joining technology (ARCJoinT) is given in Fig. 1. The joining process begins with the application of a carbonaceous mixture in the joint area, holding the pieces to be joined in a fixture, and curing at 110-120°C for 10 to 20 minutes. This step fastens the pieces together. Silicon or a silicon-alloy in tape, paste, or slurry form is applied around the joint region and heated to1250-1425°C (depending on the type of infiltrant) for 10-15 minutes. The molten silicon or silicon- refractory metal alloy reacts with carbon to form silicon carbide with controllable amounts of silicon and other phases as determined by the alloy composition. Joint thickness can be readily controlled in this process by controlling the properties of the carbonaceous paste and applied fixturing force.

At NASA-Lewis, a wide variety of silicon carbide-based ceramics and fiber reinforced composites, consisting of different sizes and shapes, have been joined using this technology as shown in Figs. 2 and 3. They include Cerastar™ Reaction-Bonded Silicon Carbide (Cerastar RB-SiC) obtained from Carborundum Co., Gardener, MA; Hexoloy-SA™ (sintered alpha-SiC) from Carborundum Co., Niagara Falls, NY, and a wide variety of carbon and silicon carbide fiber reinforced silicon carbide matrix composites (C/SiC and SiC/SiC). After joining, the microstructure and mechanical properties of the joints were characterized at different temperatures. There is the potential to extend this joining approach to the repair of silicon carbide-based ceramic and composite components damaged in service.

Joint Microstructure

The optical micrographs of joints in Cerastar™ RB-SiC and Hexoloy-SA materials are presented in Fig. 4 (a) and (b). These joints contain silicon carbide and silicon. Reaction formed joints with different thicknesses have been fabricated using this process. The joint thickness and composition have a strong influence on both the low and high temperature properties of the joined materials. The micrograph in Fig. 4 (a) also shows a non-uniform distribution of coarse and fine silicon carbide grains (gray) in a silicon phase (white) in the bulk material. In addition, this material contains areas with large pools of silicon and some porosity. As shown in Fig. 4 (b), there is some residual porosity in the microstructure of as-received sintered SiC (Hexoloy-SA™).

For the preparation of specimens for mechanical testing, bars were cut from large plates and the as-machined surfaces were used for joining. Before joining, the bars were cleaned in acetone and dried. Flexure test specimens were machined from the joined bars, with joints centrally located. Four-point flexural strength testing was carried out using the MIL-STD-1942 (MR) configuration B specimens with 20 mm inner and 40 mm outer spans. Flexure tests were conducted at 23°C, 1200°C, and 1350°C in air. Six to nine specimens were tested at each temperature. After testing, fracture surfaces were examined by optical and scanning electron microscopy to identify the failure origins.

Mechanical Strength

A summary of flexural strengths of the as-received and joined Cerastar RB-SiC materials is shown in Fig. 5 (a). The average room temperature strengths of as-received and joined specimens were 157±11 MPa and 147±10 MPa, respectively. The flexural strength of as-received and joined bars increases at high temperatures. Healing of machining flaws is one possible explanation. The flexural strengths of joined bars are comparable to those of as-received materials. The fracture origins appeared to be inhomogeneities inside the parent material.

The flexural strength data for as-received and joined sintered silicon carbide (Hexoloy-SA) are shown in Fig. 5 (b). The 23°C, 1250, and 1350°C flexural strength of as-received Hexoloy-SA specimens were 402±26, 392±8, and 402±9 MPa, respectively. The joined Hexoloy-SA specimens with 45-50 μm thick joints had strengths of 275±13, 302±17, and 297±15 MPa, respectively. In the joined Hexoloy-SA materials fracture does initiate in the joint region. Inhomogeneous silicon distribution has been observed in certain areas of the joint. Efforts are underway to fabricate joints with more homogeneous microstructure and composition, vary the joint thickness, and evaluate the effect of high temperature heat treatment on the joint strength in these materials.

Conclusions

It has been demonstrated that the ARCJoinT approach can be used to produce strong joints in commercially available reaction-bonded and sintered silicon carbide-based materials. These joints maintain their strength up to 1350°C in air. The joining technology is affordable and robust, and it can be used for the joining of large and complex shaped components. With further development, it can be adapted to the repair of silicon carbide-based ceramic and composite components in the field.

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Figure Captions

Fig. 1: Schematic of ARCJoinT process for joining silicon carbide-based ceramics and fiber reinforced composites.

Fig. 2 : Components fabricated from joined silicon carbide-based ceramics sub-elements.

Fig. 3 : Photographs showing components fabricated from joined fiber reinforced silicon carbide matrix composite sub-elements.

Fig. 4 : Microstructure of reaction formed joints in (a) Cerastar™ RB-SiC (~50-55 μm thick) and (b) sintered SiC (Hexoloy-SA™) (~50-55 μm thick).

Fig. 5 : Flexural strengths of as-received and joined Cerastar RB-SiC; (b) sintered SiC at low and high temperatures.

Affordable, Robust Ceramic Joining Technology (ARCJoinT)

Apply Carbonaceous Mixture to Joint Areas
Cure at 110-120°C for 10 to 20 minutes

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Apply Silicon or Silicon-Alloy
(paste, tape, or slurry)
Heat at 1250-1425°C for 10 to 15 minutes

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Affordable, Robust Ceramic Joints with Tailorable Properties

CD-97-74562

Fig 1

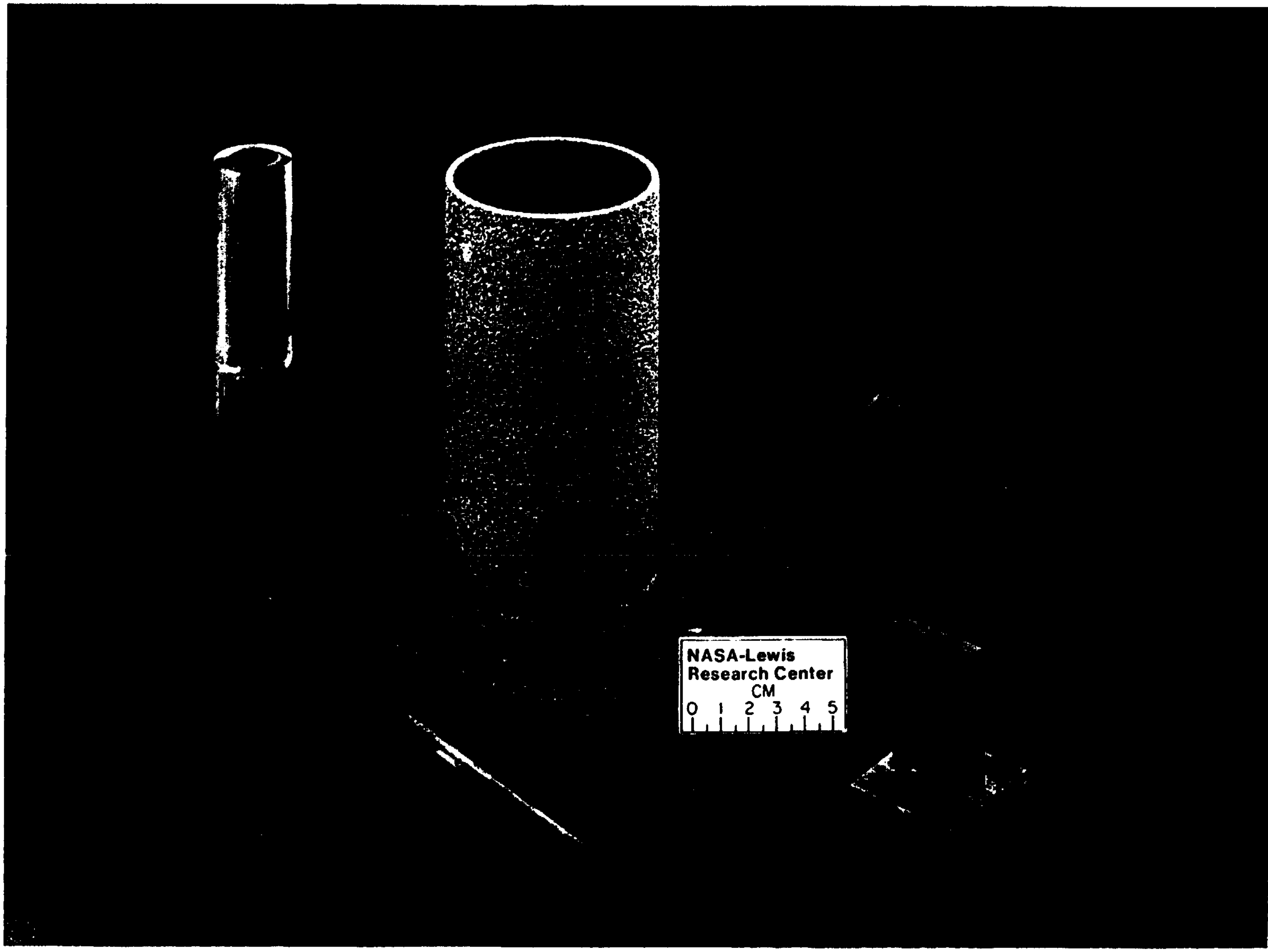


Fig 2

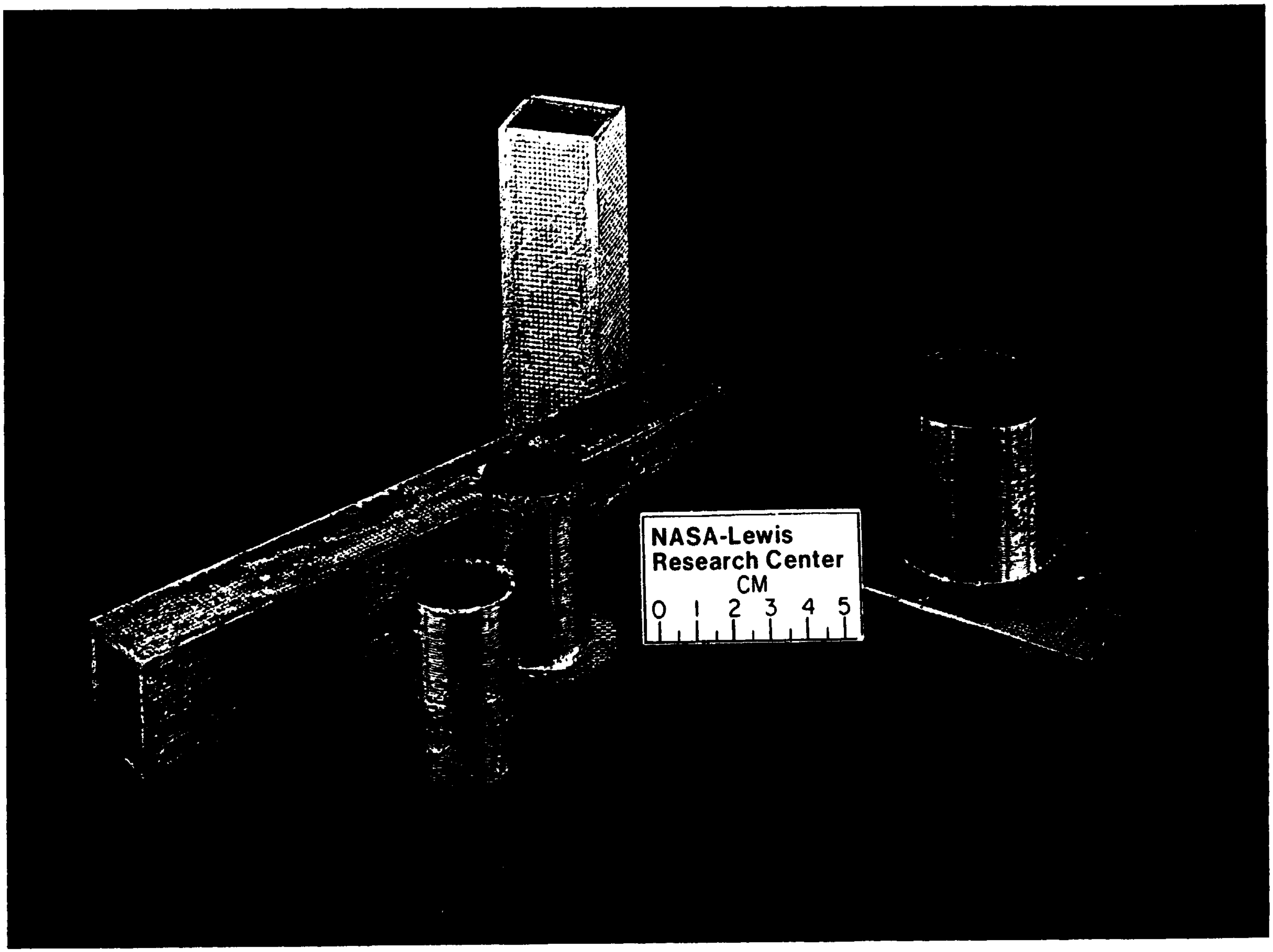
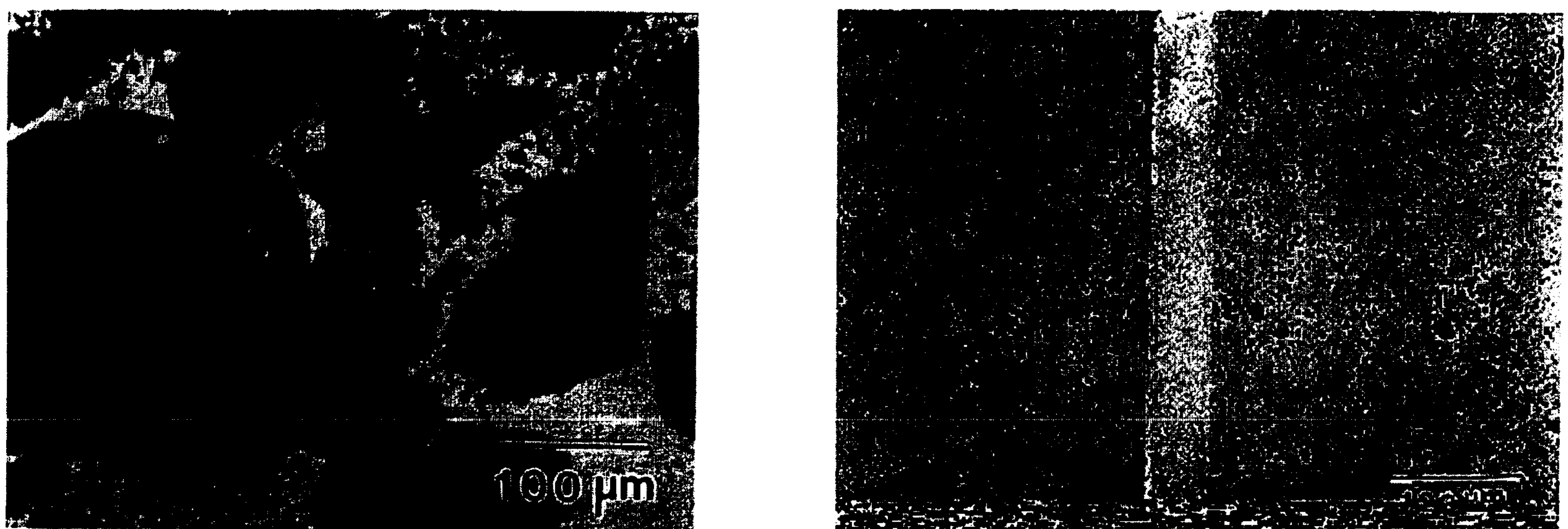


Fig. 3



~ 50-55 µm
a

?

~ 50-55 µm
b

Fig. 4

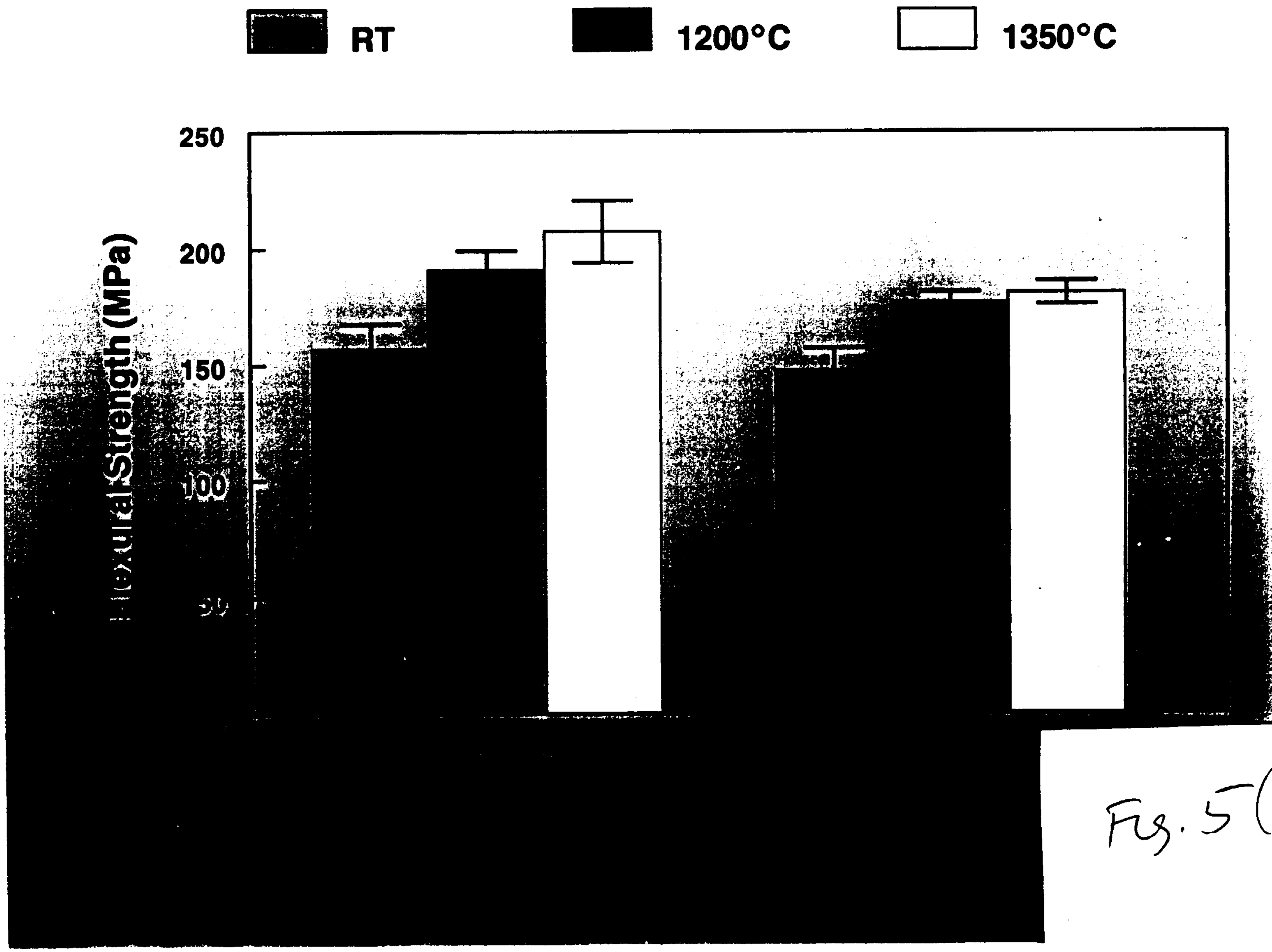


Fig. 5(a)

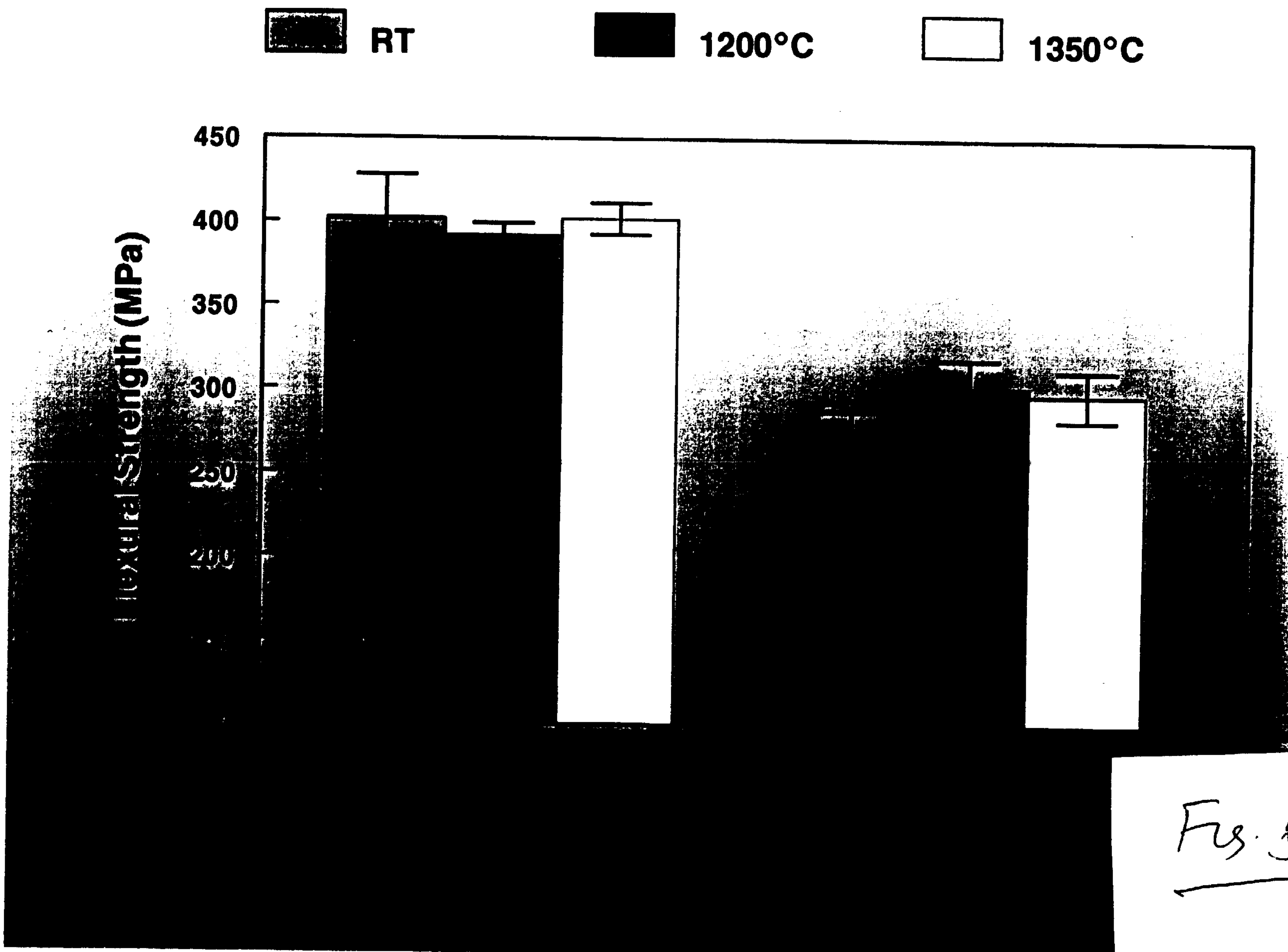


Fig. 5(b)